NATIONAL EXPOSURE CLASSES OF CONCRETE IN HUNGARY

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Dedicated to Prof. György L. Balázs
for his 65th birthday

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Sufficient durability of concrete and reinforced concrete structures is always required, mainly if it is exposed to extraordinary (severe) environmental attack - much over the well-known classes in European Standard for Concrete EN 206. In this case, appropriate concrete composition (e.g. special binders, etc.), strength, low porosity and sufficient concrete cover are required to withstand these special environmental exposures. The present paper deals with the additional exposure classes for these severe cases added to the Hungarian Standard MSZ 4798, which is the national version of EN 206. Maybe CEN could also use and add some of these "X-new" classes in the following version of the standard EN 206.

Keywords: chemical attack, abrasion, water head, concrete corrosion, concrete exposure class

1. INTRODUCTION

Hungary has been a full member of CEN (Comité Européen de Normalisation) since 1 January 2003 and has to introduce the European standards EN (Normes Européennes) with unchanged content within six months of publication. (The MSZ designation is derived from the "Hungarian Standard" initials.) For example, the Hungarian version of the European concrete standard EN 206 is marked MSZ EN 206, and the Hungarian national application document (NAD) of the standard MSZ EN 206 is marked MSZ 4798.

In the Hungarian standard MSZ 4798, the exposure classes of concrete are given special attention. N*ew Hungarian exposure classes* have been introduced, which represent the extension and supplementation of the exposure classes of EN 206. The sign for the new Hungarian exposure classes contains in parenthesis the internationally approved country sign (H) of Hungary, for example:

- sign of the Hungarian exposure class of concrete with a subordinate role: XN(H);
- sign of the Hungarian exposure class of concrete not exposed to harmful environmental effects: N0b(H);
- the symbol of the Hungarian exposure class X0v(H) means a slightly reinforced concrete that will not be exposed to any adverse environmental effects other than carbonation;
- sign of the Hungarian exposure class of concrete exposed to freeze-thaw: XF2(H) – XF4(H) *without entrained air* ("air bubbles);
- sign of the Hungarian exposure class of concrete exposed to chemical corrosion by aggressive rainwater, wastewater, liquids, condensation water and vapours: XA4(H) – XA6(H);
- sign of the Hungarian exposure subclass of concrete in the ground, in wet environments but not exposed to water pressure: XV1(H)/V0;
- sign of the Hungarian exposure class of concrete exposed to water pressure: XV1(H) – XV3(H);
- sign of the Hungarian exposure class of concrete exposed to abrasion (wear): XK1(H) – XK4(H).

Annex F of the standard MSZ 4798 (similar to EN 206) containing the limit values of concrete compositions belonging to the exposure classes (together with the amendments, e.g.: MSZ 4798:2016/2M:2018 and MSZ 4798:2016/4M:2023) are requirements, which must be complied with.

2. HUNGARIAN EXPOSURE CLASSES FOR NO RISK OF CORROSION OR ATTACK

If the concrete of subordinate strength, such as a base concrete, concrete base layer, cement stabilisation, etc., is not exposed to an adverse environmental impact, the concrete shall be classified in exposure class XN(H).

Concrete of higher strength, such as base concrete, backing and backing concrete, hand-held masonry concrete units, etc., which are not adversely affected by the environment, are classified in exposure class X0b(H).

Concrete of slightly reinforced concrete structures, such as demarcated concrete, etc., may be classified in exposure class X0v(H) if the concrete is not exposed to any adverse environmental effects other than carbonation. A slightly reinforced concrete structure shall be considered as one in which the total cross-sectional area of the steel - that can be taken into account in verifying compliance with the load-bearing requirements - is less than the minimum required for the dimensioning and/or construction of load-bearing reinforced concrete structures.

Concrete classified in exposure classes XN(H), X0b(H) and X0v(H) shall have a composition in accordance with *Table 1*.

3. HUNGARIAN SUPPLEMENT TO THE EXPOSURE CLASSES FOR RISK OF CORROSION INDUCED BY CHLORIDES

Concrete of reinforced concrete or prestressed concrete structures in contact with aggressive water (groundwater, other natural water, sewage or other aggressive liquids) shall

Table 1: Limits for concrete composition in case of no risk or effect of corrosion

Requirements	Hungarian exposure classes		
	XN(H)	X0b(H)	X0v(H)
Maximum water/cement ratio	0.90	0.75	0.70
Minimum strength class	C8/10	C12/15	C16/20
Minimum cement content, kg/m^3	165	230	250
Planned air content of fresh concrete	*See Table 6*		

be classified as exposure class XD2 only if the chloride ion content (Cl^-) of the aggressive water is more than 500 mg/litre.

Concrete exposed to both frost and deicing agents shall be classified in one of the exposure classes XF2, XF2(H), XF4 or XF4(H) instead of the exposure class XD.

4. HUNGARIAN EXPOSURE CLASSES FOR RISK OF FREEZE/THAW ATTACK

According to Table F.1 of European Standard EN 206, concrete of exposure classes XF2, XF3 and XF4 exposed to freezing shall be made of fresh concrete with an air content of at least 4.0% by volume, which means that concrete of exposure classes XF2, XF3 and XF4 shall be made of air-entrained concrete with an air-entraining admixture ("air bubbles").

In Hungary, concrete exposed to frost and a deicing agent is allowed to be made *without air-entraining* admixture if it is *not made for road or airport pavement*. Such concrete without artificial air bubbles shall be classified in accordance with standard MSZ 4798 as XF2(H), XF3(H) and XF4(H).

In exposure class XF2(H) (characterised by moderate water saturation, with a deicing agent), infrastructural constructions (e.g. bridges, roads), other monolithic structures and precast concrete products with a vertical or steeper surface than 5%, made *without air entraining agent*, are classified as XF2(H), if they are exposed to frost and saltwater spray.

In exposure class XF3(H) (characterised by high water saturation, without deicing agent), infrastructural constructions (e.g. bridges, roads), other monolithic structures and precast concrete products with a horizontal or a maximum slope of 5%, made *without air entraining agent*, are classified as XF3(H) if they are exposed to frost and water.

In exposure class XF4(H) (characterised by high water saturation, with deicing agent), infrastructural constructions (e.g. bridges, roads), other monolithic structures and precast concrete products with a horizontal or a maximum slope of 5%, made *without air entraining agent*, are classified as XF4(H) if they are exposed to frost, precipitation and salt.

The inclination angle of the 5% elevation or inclination surface is arctg (0.05) ~ 2.86°.

The composition requirements for concrete classified in exposure classes XF2(H), XF3(H) and XF4(H) are *given in Table 2*.

Concrete with a horizontal slope and not more than 10 metres from the traffic surface or with a slope of not more than 5%, exposed to water splashing from a traffic surface or to water spray from the traffic surface, shall be classified in exposure class XF3 or XF3(H).

If the water or the water spray contains salt, the concrete with a horizontal surface or a slope of not more than 5% and not farer than 10 m from the traffic surface is classified in exposure class XF4 or XF4(H).

Concrete of exposure classes XF2, XF3 and XF4 may be made with silica fume only if the water/binder ratio is less than or equal to 0.37 and the set of such concrete is not delayed by a two-effect admixture.

The frost resistance and the frost and melting salt resistance of all XF and XF(H) exposure classes of concrete shall be carried out by slab test method (reference method) or with cube test method or CD/CDF test method in accordance with CEN/TS 12390-9 technical specification. The test procedures are given in *Table 3,* and the specifications for the permissible amount of scaled-down material are given in *Table 4*.

The Hungarian requirements for the air-bubble structure of hardened frost- and deicing agent resistant concrete made with air entraining admixture are *given in Table 5.*

Table 2: Limits for the composition of frost resistant and frost – and salt resistant concrete made without air entraining agent

Requirements	Hungarian exposure classes		
	XF2(H)	XF3(H)	XF4(H)
Maximum water/cement ratio	0.50	0.45	0.40
Minimum strength class	C35/45	C40/50	C40/50
Minimum cement content, kg/m^3	320	340	360
Planned air content of fresh concrete	*See Table 6*		
Other requirements	The use of these exposure classes is prohibited for road and airport pavements. The aggregate for concrete shall be frost- and melting salt-resistant.		

Table 3: Conditions for the performance of the concrete CEN/TS 12390-9 Technical Specification frost resistance and frost and deicing salt resistance test applied in Hungary

Frost resistance test
XF1 exposure class concrete
The frost resistance test may be omitted upon agreement if the concrete composition meets the requirements of exposure class XF1.
XF3 exposure class concrete
The concrete shall comply with the freeze resistance requirement for concrete of exposure class XF3 according to one of the test methods in *Table 4*. The frost resistance test may be omitted upon agreement if the hardened concrete air bubble structure meets the requirements of *Table 5*.
XF3 exposure class concrete
The concrete shall comply with the freeze resistance requirement for concrete of exposure class XF3 according to one of the test methods in *Table 4*.
Resistance to freezing and deicing salt test
XF2 exposure class concrete
The concrete shall comply with the freeze and deicing agent resistance requirements for exposure class XF2 according to one of the test methods in *Table 4*. The frost and melting salt resistance test may be omitted upon agreement if the hardened concrete air bubble structure meets the requirements of *Table 5*.
XF2(H) exposure class concrete
The concrete shall comply with the freeze and deicing agent resistance requirement for concrete of exposure class XF2(H) according to one of the test methods in *Table 4*.
XF4 exposure class concrete
The concrete shall comply with the freeze and deicing agent resistance requirement for concrete of exposure class XF4 according to one of the test methods in *Table 4*. Upon agreement, the frost and deicing salt resistance test can be omitted if the air void indices (bubble) structure of the hardened concrete meets the requirements of *Table 5*.
XF4(H) exposure class concrete
The concrete shall comply with the freeze and deicing agent resistance requirement for concrete of exposure class XF2(H) according to one of the test methods in *Table 4*. The water tightness of hardened concrete shall also be checked in accordance with EN 12390-8, and the maximum individual water penetration value shall not exceed 20 mm as determined from at least 3 test specimens.

5. HUNGARIAN ADDITIONS TO THE REQUIREMENTS FOR THE FRESH CONCRETE AIR CONTENT AND THE AIR VOID (BUBBLE) STRUCTURE OF THE HARDENED CONCRETE

In Table F.1 of European Standard EN 206, a minimum air content of 4.0% by volume for concrete of environmental classes XF2, XF3 and XF4 is demanded, though it is not cleared up in the standard, whether the sum of the air-pore (entrapped air) content and the air-bubble (entrained air) content of fresh concrete is given. The latter is measured by the compression method. These figures may be very small in some cases, but in the absence of other more accurate data, it is suitable for use in the first approximation to design the approximate composition of frost and deicing agent resistant fresh concrete with the above ones.

In Hungary, the composers of the standard MSZ 4798 clarified the air content of fresh concrete made *without air entraining agent* (*Table 6*) and *the total air content* of fresh concrete made *with air entraining agent* (*Table 7*).

6. HUNGARIAN EXPOSURE CLASSES IN RISK OF CHEMICAL ATTACK

In Table 1 and Table F.1 of European Standard EN 206, concrete is supposed to be exposed only to chemical corrosion by soil and natural groundwater and is classified for these hazards in environmental classes XA1, XA2 and XA3. In the Hungarian standard MSZ 4798, the conditions for the classification of concrete in contact with aggressive rainwater, municipal water, industrial and agricultural wastewater, condensation water and other aggressive liquids, gases, vapours, sprays and fermentation materials are defined as XA4(H), XA5(H) and XA6(H).

Classified in exposure class **XA4(H)**:

a) concretes in contact with *slightly* aggressive liquids, which can be discharged into the public sewer,

Table 4: *Requirements for the concrete CEN/TS 12390-9 technical specification frost resistance and frost and melting salt resistance test applied in Hungary.*

	Frost resistance test	Resistance to freezing and melting salt test
Slab test method		
Freezing liquid	3 mm deep deionised water	3 mm deep 3% NaCl solution
Maximum permissible mass of exfoliated material, g/m^2	XF1 class	XF2 and XF2(H) class
	average: 1500, single value: 2000	
	XF3 and XF3(H) class	XF4 and XF4(H) class
	average: 1000, single value: 1350	
Cube test method		
Freezing liquid	Deionised water covering the test specimen at a height of 25 ± 5 mm	3% NaCl solution covering the test specimen at a height of 25 ± 5 mm
Maximum permissible mass of exfoliated material, % w/w	XF1 class	XF2 and XF2(H) class
	average: 6.5, single value: 7.5	
	XF3 and XF3(H) class	XF4 and XF4(H) class
	average: 4.0, single value: 5.0	
CD/CDF test method		
Freezing liquid	10 mm deep deionised water	10 mm deep 3% NaCl solution
Maximum permissible mass of scaled down material, g/m^2	XF1 class	XF2 and XF2(H) class
	average: 1500, single value: 2000	
	XF3 and XF3(H) class	XF4 and XF4(H) class
	average: 1000, single value: 1350	

Table 5: *Requirements for the air bubble structure of hardened, frost and deicing agent resistant concrete made with air-entraining admixture in Hungary*

Exposure class	XF2 and XF3	XF4
Spacing factor, max. mm,	0.22	0.18
Amount of air bubbles (effective) with nominal diameter less than 0.3 mm, min. V%	1.2	2.2
Note: The spacing factor of hardened concrete with air bubbles and the amount of effective air bubble volume shall be measured in accordance with EN 480-11.		

Table 6: *Planned air content of fresh concrete to be made without air entraining agent in Hungary*

Consistency	Slump classes	—	S1	S2, S3	S4, S5
	Compaction classes	C1	C2	C3	C4
	Flow classes	F1	F2	F3	F4, F5, F6
Compressive strength class		Planned fresh concrete air content, up to, % V/V			
C8/10		5.0	4.0	3.0	2.0
C12/15		4.0	3.0	2.0	1.5
C16/20		3.5	2.5	1.5	1.0
C20/25		3.0	2.0	1.0	1.0
C25/30		2.0	1.5	1.0	1.0
C30/37		1.5	1.0	1.0	1.0
C35/45 – C100/115		1.0	1.0	1.0	1.0
In the case of prestressed concrete, the air content of fresh concrete should be 20% lower than the above volumetric values if the volume is ≥ 1.5 V%. In the case of concrete with crushed stone aggregate, the fresh concrete may have an air content 25V% higher than the above-listed values - excluding the exposure classes XK2(H), XK3(H) and XK4(H), planned for abrasion-resistant concretes.					

Table 7: Planned total air (air-pore + air-bubble) content of fresh concrete in Hungary made with air-entraining agent

Exposure class	XF2 and XF3	XF4
Maximum size of the aggregate, mm	Total fresh concrete air (air-pore content + air-bubble content), % Vol	
8 and 12	4.0 – 6.0	6.0 – 10.0
16	3.0 – 5.0	4.5 – 8.5
24 and 32	2.5 – 5.0	4.0 – 8.0
63	2.0 – 4.0	3.0 – 7.0
In the case of prestressed concrete, the air content of fresh concrete should be 20% lower than the above values if its volume is ≥ 1.5 V%. In the case of concrete with crushed stone aggregate, the fresh concrete may have an air content 25% higher than the above values, excluding the exposure classes XK2(H), XK3(H) and XK4(H), planned for abrasion-resistant concretes.		

- such concrete is, e.g. that of the tertiary (physicochemical) treatment structures of the *newly established* wastewater treatment plants, regardless of the chemical characteristics, according to *Table 8*.
- if the *existing structure is in contact with slightly aggressive* liquids and *renovated or enlarged*, the new concrete shall be classified in the environmental class according to *Table 8*.

b) and concretes near *slightly* aggressive waters and liquids, gases, vapours, sprays, and fermenting substances. Concrete of rainwater storage structures, etc. - in contact with slightly aggressive chemicals - shall be classified in the environmental class according to *Table 8*.

Acid rains act intermittently, it is generally sufficient to classify the concrete as XA4(H).

Classified in exposure class **XA5(H)**:

a) concretes in contact *with moderately* aggressive liquids, which can be discharged into the public sewer,
- Such are the *newly established* sewers, shafts, public area pumping stations and primary (mechanical and secondary, biological treatment structures of the wastewater treatment plant, as well as the concrete of the wastewater sludge treatment structures, regardless of the chemical characteristics according to *Table 8*.
- If the *existing structure in contact with moderately aggressive* liquids is renovated or enlarged, the new concrete shall be classified in the environmental class according to *Table 8*.

b) and concretes in the vicinity of *moderately aggressive* waters and liquids, gases, vapours, sprays, and fermenting substances. Concrete of other concretes, slurry storage and treatment pools, stall floors, leachate storage pools, crops storage facilities, chimney wreaths, etc., in contact with moderately aggressive chemicals shall be classified in the environmental class according to *Table 8*.

Classified in exposure class **XA6(H)**:

a) concretes in contact with *highly aggressive* liquids which *cannot* be discharged into the public sewer,
- Such are the *newly established sewers,* shafts, pumping stations and wastewater treatment plant structures, regardless of the chemical characteristics, according to *Table 8*.
- If the *existing structure in contact with highly aggressive* liquids is renovated or expanded, the new concrete shall be classified in the environmental class according to *Table 8*.

b) and concretes in the vicinity of *highly aggressive* waters and liquids, gases, vapours, sprays, and fermenting substances. Concrete of other concretes, cooling towers with or without flue gas discharge, animal feeding troughs, feed silos, agricultural fermentation silos, wood drying halls, railway car wash facilities, hazardous waste storage facilities, etc., in contact with highly aggressive chemicals shall be classified in the environmental class, according to *Table 8*.

The limit values for the chemical characteristics of the exposure classes XA4(H), XA5(H) and XA6(H) are *given in Table 8*.

The composition requirements for XA4(H), XA5(H) and XA6(H) exposure classes are *given in Table 9*.

7. DETERMINATION OF SULPHATE CONTENT

The sulphate ion (SO_4^{2-})-content of soil and groundwater for the classification of concrete as XA1, XA2 and XA3 and of the wastewater and other aggressive waters and liquids for the classification of concrete as XA4(H), XA5(H) and XA6(H) shall be determined by the test method in accordance with EN 206 and MSZ 4798, respectively, in accordance with the test method in accordance with EN 196-2.

In our case, the sulphate content is determined not on cement but on concrete corrosive materials. Some steps of the test method according to EN 196-2 cement test standard should be regulated accordingly.

7.1. Determination of sulphate content of soils

7.1.1 Determination of sulphate content of soils by hydrochloric acid process

For the classification of concrete in environmental classes XA1, XA2 and XA3, the soil sample of at least 2 kg taken from the soil to be tested shall be reduced to 250 g by quartering step by step. This part shall be dried at a temperature of 110 ± 5 °C and then chopped to a grain size of less than 0,5 mm. For the test, 50 g of dried, shredded soil sample is used, which is allowed to stand for 24 hours when poured with 150 ml of distilled water. The next day, the soil sample poured over with distilled water shall be shaken for 1 hour on a shaker, filtered into a 250 ml volumetric flask and washed with additional distilled water until a volume of 250 ml has been reached. If the filtrate is cloudy, it should be settled by centrifugation, and a clear portion of the solution should be used for further testing.

Table 8: Limits for exposure classes for chemical corrosion by waste waters and other aggressive waters, liquids, gases, vapours, sprays and fermenting substances

Chemical Characteristic	Test method	Hungarian exposure classes		
		XA4(H)	XA5(H)	XA6(H)
pH Value Acid attack corrosion. In the case of sulfuric acid corrosion, additional sulphate attack corrosion, too	EN ISO 10523 (Reference method) EN 15933 MSZ 260-4 MSZ 1484-22	≤ 6.5 and ≥ 5.0	< 5.0 and ≥ 4.0	< 4.0 and ≥ 3.5
Water hardness Acid attack corrosion	MSZ 448-21	≥ 3 and ≤ 7 ºdh or ≥ 0.54 and ≤ 1.25 mmol/litre of soft water	< 3 ºdh or < 0.54 mmol/litre of very soft water	
Aggressive carbon dioxide (CO_2) dissolved in water, mg/litre Acid attack corrosion	EN 13577 (Reference method) MSZ 448-23	≥ 15 and ≤ 40	> 40 and ≤ 100	> 100
Magnesium ion (Mg^{2+}), mg/litre Acid attack corrosion	EN ISO 7980 (Reference method) EN ISO 14911 MSZ 260-52 MSZ 1484-3	≥ 100 and ≤ 1000	> 1000 and ≤ 2500	> 2500
Ammonium ion (NH_4^+), mg/litre Acid attack corrosion	ISO 7150-1 (Reference method) EN ISO 14911 MSZ 260-9	≥ 15 and ≤ 30	> 30 and ≤60 In the case of sewage: > 30 and ≤ 100	>60 > 100
SO_4^{2-}content, mg/litre Sulphate attack corrosion	EN 196-2	≥ 200 and ≤ 600	> 600 and ≤ 1500	> 1500
Additional requirements for new concrete for existing structures, for structures to be renovated or enlarged, exposed to aggressive liquids causing chemical corrosion				
The ratio of dichroic chemical oxygen demand (DCOD) and 5-day biochemical oxygen demand (BOD5), DCOD/BOD5 Acid attack corrosion	DCOD, for mg/litre: ISO 6060 BOD5, for mg/litre: EN ISO 5815-1, EN 1899-2	≥ 4	< 4.0 and ≥ 2.5	< 2.5
Oxidation-reduction potential (ORP), mV Acid attack corrosion	ASTM D1498-14	≤ -50 and ≥ -100	< -100 and ≥ -150	< -150

Table 9: Limits for the composition of concretes exposed to corrosion by waste waters and other aggressive waters, liquids, gases, vapours, sprays and fermenting substances

Requirements for the addition of a type II supplement	Hungarian exposure classes		
	XA4(H)	XA5(H)	XA6(H)
Maximum water/(effective binder) ratio	0.45	0.43	0.40
Minimum strength class	C30/37	C30/37	C35/45
Cement content, kg/m^3	320-365	330-380	345-395
Planned air content of fresh concrete	*See Table 6*		
Maximum depth of water penetration tested in accordance with EN 12390-8, mm	average: 20, single value: 22		

For the gravimetric determination of sulphate ions according to EN 196-2 paragraph 4.4.2.2, 100 ml of this filtrate shall be measured, the hydrogen ion concentration of which shall be adjusted to pH = 1.0-1.5 with 1+11 dilution hydrochloric acid (HCl). The sulphate ions produced when the sample is excavated with hydrochloric acid are separated with barium chloride ($BaCl_2$-) solution at pH 1.0-1.5, as described in EN 196-2. Wash the separated and fine pore-filtered solution with boiling water to a chloride-free state and heat to constant weight at 950 ± 25 ºC. The mass of the barium sulphate thus obtained ($m_{bariumsulphate}$) multiplied by 0.343 is the mass of SO_3 (sulphur trioxide), from which the *sulphite* content of the soil, expressed as SO_3, is calculated as a percentage by the following equation:

$$SO_3^{[\%]} = \frac{m_{bariumsulphate} \times 0.343046 \times 100}{m_{soil\ sample}} = 34.30 \times \frac{m_{bariumsulphate}}{m_{soil\ sample}} = \frac{SO_3^{[mg/kg]}}{10000}$$

The conversion factor of 0.343 in the formula is the ratio of the relative molecular weight of the *sulphite* ion (SO_3) and the barium sulphate ($BaSO_4$): 80.06/233.38 = 0.343046.

For the classification of concrete in the environmental class in Table 2 of EN 206, the limit values for the sulphate content of the soil are not given in SO_3 [%] (sulphite), but SO_4 [mg/kg] (sulphate); therefore, the percentage *sulphite* ion content in EN 196-2 shall be converted to the_sulphate ion content expressed in mg/kg. The conversion formula is $SO_4^{[mg/kg]} = 1.2 \times SO_3^{[mg/kg]} = 1.2 \times 10^4 \times SO_3^{[\%]}$ because the relative molecular weight of the sulphate ion (SO_4^{2-}) is 96.06, the relative molecular weight of the sulphite (SO_3^{2-}) is 80.06, and their ratio is 1.2.

The sulphate ion content of the soils, expressed in mg/kg, required for the classification of the concrete in environmental class XA1, XA2 or XA3 according to EN 206 shall be obtained by multiplying the percentage test result expressed as $SO_3^{\%}$in accordance with EN 196-2 by 1.2×10^4:

$$SO_4^{\left[\frac{mg}{kg}\right]} = 1.2 \times 10^4 \times SO_3^{[\%]} = 411655 \times \frac{m_{bariumsulphate}}{m_{soil\ sample}}$$

If the sulphate ion content in the 50:250 = 1:5 soil sample extract test is more than 6000 mg/kg, the test shall be repeated with a 1:10 soil sample extract test.

7.1.2 Determination of sulphate content of soils by aqueous process

According to Table 2 of EN 206, the sulphate content of soils may be determined by the aqueous process instead of the hydrochloric acid process if there is experience.

In this case, the determination is carried out with a sample prepared in accordance with EN 1744-1. The soil sample of at least 2 kg shall be reduced to 250 g by quartering step by step. This part shall be dried at a temperature of 110 ± 5 °C and then chopped to a grain size of less than 0.125 mm until at least 20 g of soil sample has fallen through a sieve with a mesh size of 0.125 mm.

The test is then carried out according to EN 196-2 paragraph 4.4.2.2 by weighing 2.00 + 0.05 g of powdered sample. The test result:

$$SO_4^{\left[\frac{mg}{kg}\right]} = 411655 \times \frac{m_{bariumsulphate}}{m_{soil\ sample}}$$

7.2. Determination of sulphate content of groundwater, wastewater and other aggressive liquids

Concrete in contact with sulphate-containing groundwater is classified in exposure class XA1, XA2 or XA3 and concrete in contact with sulphate-containing sewage or other aggressive liquids is classified in exposure class XA4(H), XA5(H) or XA6(H).

For the classification of concrete as XA1, XA2, XA3, XA4(H), XA5(H) or XA6(H), the sulphate content of the groundwater, rainwater, wastewater or other aggressive liquids, etc., surrounding the concrete shall be determined by the method in accordance with the EN 196-2 cement test standard and expressed in mg/litre.

When determining the sulphate content of groundwater, rainwater, wastewater or other aggressive liquids, etc., the procedure according to paragraph 4.4.2.2 of EN 196-2 cement test standard is modified by using 250 ml of filtered groundwater, wastewater or other aggressive liquids, etc., instead of cement pulp, whose pH value is adjusted to 1.0-1.5 with 1+11 dilution hydrochloric acid. This solution shall be used for the gravimetric determination of sulphate ions, hereinafter referred to as 'Bring to the boil and boil for 5 minutes', according to EN 196-2 paragraph 4.4.2.2. beginning with the fourth paragraph.

The test result in this case:

$$SO_4^{\left[\frac{mg}{kg}\right]} = 411655 \times \frac{m_{bariumsulphate}}{m_{soil\ sample}}$$

8. WATERTIGHT CONCRETE AND CONCRETE EXPOSED TO WATER ABSORPTION, HUNGARIAN EXPOSURE CLASSES

According to the standard MSZ 4798, concrete shall be classified in

- exposure class XV1(H), if the *water column* pressure is > 100 mm and < 2000 mm;
- exposure class XV2(H), if the *water column* pressure is > 2000 mm and < 10000 mm;
- exposure class XV3(H), if the *water column* pressure is > 10000 mm.

The concrete is categorised as exposure class XV1(H) if the hydrostatical head is less than 2 m (e.g. cellar walls, rainwater drainages, cisterns, water culverts, gutters, downpour reservoirs, rainwater collector shafts, etc.).

The concrete is categorised as exposure class XV2(H) if the hydrostatical head is between 2 m and 10 m (e.g. channels, dams, river walls, outer boundary structures of underground garages and subways, hydraulic engineering structures, etc.).

The concrete is categorised as exposure class XV3(H) if the hydrostatical head is more than 10 m (e.g. outer boundary structures of underground parking garages and tunnels, hydraulic engineering structures, etc.).

According to the standard EN 12390-8, the highest allowed individual depth values of water penetration (measured on three different specimens) into the concrete of exposure classes XV1(H), XV2(H) and XV3(H), respectively, are summarised in Table 10.

Water is considered to be not under pressure if the water head is ≤ 100 mm. For example, concrete embedded in a wet medium is exposed to water without pressure. Furthermore, concrete surrounded with soil moisture basements above the groundwater level is classified into exposure subclass XV1(H)/V0 according to MSZ 4798 upon their water absorption. Such are, e.g. basements or cellar walls above groundwater level that are exposed to soil moisture or vapours

Table 10: Limits for the composition of watertight concrete and concretes exposed to water absorption

Requirements	Hungarian exposure classes			
	Impact: water absorption	Impact: water pressure		
	XV1(H)/V0	XV1(H)	XV2(H)	XV3(H)
Maximum water/cement ratio	0.55	0.55	0.50	0.45
Minimum strength class	C25/30	C25/30	C30/37	C30/37
Minimum cement content, kg/m^3	300	300	300	300
Planned air content of fresh concrete	*See Table 6*			
Other requirements	The coefficient of water absorption of concrete (determined according to the standard EN ISO 15148) should be $W_{wt} \leq 2{,}0$ kg/(m^2·h^{½}).*	Maximum individual water penetration depth tested on min. 3 specimens in accordance with EN 12390-8, mm		
		50	35	20

* Remind: for the internal plaster hindering the wettening, see the text above Table 10.

or concretes in the vicinity of underground parking garages, where the water pressure has been permanently eliminated, e.g. by groundwater level lowering. The environmental subclass XV1(H)/V0 may also be suitable for limiting the water absorption of other structures, such as concrete block walls, that come into contact with the ground on one side, generally together with other exposure classes.

XV1(H)/V0 exposure subclass concrete shall not be considered watertight concrete.

The concrete of a structural element exposed to environmental moisture but not to water pressure can be categorised as exposure subclass XV1(H)/V0 if its water absorption coefficient – determined according to the standard EN ISO 15148 – is: $W_{wt} \leq 2{,}0$ kg/(m^2·h^{½}).

The concrete categorised as exposure subclass XV1(H)/V0 *is not watertight*, therefore – depending on the thickness of the structural element and Darcy's water permeability coefficient (according to standard EN ISO 17892-11) and its temporal change. (e.g., change in the surrounding soil, embedding layer, excavation pit filling, and any unexpected water level rise – it may get wet). The recommended thickness of the wall structural element and base plate should be at least 200 mm and 150 mm, respectively, and the *k*, i.e. Darcy's water permeability coefficient (according to standard EN ISO 17892-11) of the surrounding soil, embedding layer, or excavation pit filling should be minimum $k = 5 \cdot 10^{-5}$ m/s, i.e. the material surrounding the concrete should be water permeable to avoid water stagnation.

Furthermore, the author means that the owner may prevent the risk of any possible wetting or soaking by applying (at their own charge) an internal (i.e. the side of the interior area) water-repellent plasterwork. For example:

- if the value of the concrete's water absorption coefficient (capillary water absorption number) is $W_{wt} \leq 0{,}5$ kg/(m^2·h^{½}), then it is *recommended* to apply an appropriate layer of water-repellent coating on the internal surface (interior side) of the concrete;
- if the value of the concrete's water absorption coefficient (capillary water absorption number) is $0{,}5 < W_{wt} \leq 2{,}0$ kg/(m^2·h^{½}), then it is *highly recommended* to apply an appropriate layer of water-repellent coating on the internal surface (interior side) of the concrete;

The composition requirements for concrete classified in exposure subclasses XV1(H)/V0, XV1(H), XV2(H) and XV3(H) are *given in Table 10*.

9. HUNGARIAN EXPOSURE CLASS OF CONCRETE EXPOSED TO ABRASION

According to standard MSZ 4798, if the concrete is exposed to abrasion by abrasive, sliding, rolling, frictional, impact or water flow driven rolling stock, the concrete shall be classified into environmental class XK1(H), XK2(H), XK3(H) or XK4(H).

If the loss in *volume ΔV* of concrete at 28 days age, determined by the *Böhme method* according to method B. of standard EN 14157 (using 71 ± 1.5 mm test cubes) shall not exceed:

- in the case of dry abrasion, 14000, 12000, 10000, 8000 mm^3, respectively;
- in the case of abrasion of water-saturated test, 21000, 18000, 16000, and 14000 mm^3, respectively.

Concrete is classified in the XK1(H) class if it is exposed to abrasion of light granular materials, pedestrian traffic, and blown tyre vehicles. Examples are silos, bunkers, tanks for storing lightweight aggregates, agricultural crops, etc., and concrete for sidewalks, stairs, garage floors, etc.

Concrete is classified in the XK2(H) class if it is exposed to rolling loads caused by heavy loads and to the abrasion of solid-wheeled vehicles. Examples are concrete tracks for concrete roads, forklifts, structures in contact with rolled sediment, etc.

Concrete is classified in the XK3(H) class if it is exposed to sliding-rolling loads caused by very heavy loads and to the abrasion of steel-wheeled forklifts. Examples are concrete for landing and take-off tracks and taxiways at airports, as well as floor coverings for container loading stations and heavy industry assembly halls, etc.

Concrete is classified in the XK4(H) class if it is exposed to abrasion of sliding-rolling loads caused by extremely heavy loads or if high surface accuracy and dust-freeness are required. Examples are concrete for halls, warehouses and pavements exposed to extremely heavy loads and traffic of caterpillar vehicles, hard surface dust-free industrial floor coverings without wear layer or bark reinforcement, etc.

The composition requirements for concrete classified in exposure classes XK1(H), XK2(H), XK3(H) and XK4(H) are *given in Table 11*.

Table 11: *Limits for the composition of wear/abrasion-resistant concretes*

Requirements	Hungarian exposure classes			
	XK1(H)	XK2(H)	XK3(H)	XK4(H)
Maximum water/cement ratio	0.50	0.45	0.40	0.38
Minimum strength class	C30/37	C35/45	C40/50	C45/55
Minimum cement content, kg/m^3	310	330	350	370
Planned air content of fresh concrete	*See Table 6*			

10. CONCLUSIONS

To ensure the durability of concrete, reinforced concrete and prestressed reinforced concrete structures, the concrete must be classified into exposure classes according to the standards EN 1992-1-1, MSZ EN 206, MSZ 4798, and the concrete composition must be designed to comply with the requirements *of the concrete* belonging to one or the other given exposure classes.

The exposure class is not a property of the concrete but that of the environment surrounding the concrete. The term “concrete complying with a given exposure class” means a concrete that meets all the requirements of class X, which is ordered to (Annex F).

The exposure classes in the European standard EN 206 are X0; XC1 – XC4; XS1 – XS3; XD1 – SD3; XF1 – XF4; XA1 – XA3.

These classes have been extended in the Hungarian national standard MSZ 4798 with the following ones: XN(H), X0b(H), X0v(H), XF2(H), XF3(H), XF4(H), XA4(H), XA5(H), XA6(H), XV1(H)/V0, XV1(H), XV2(H), XV3(H), XK1(H), XK2(H), XK3(H), XK4(H) – where those signed with A(H) are taking into account more severe chemical exposure.

In the standard MSZ 4798 and its amendments (for example: MSZ 4798:2016/2M:2018 and MSZ 4798:2016/4M:2023), the criteria for exposure classification are based on environmental effects that may cause concrete or steel reinforcement corrosion, - such as moisture and its forms (e.g. water, ice, steam), the *chemical composition* of air or other gases or water or other liquids, the water pressure and the degree of abrasion (wear), etc.

The requirements of the Hungarian exposure classes relate, ***on the one hand, to the concrete composition parameters***, namely the maximum permissible water-cement (*w/c*) or water-efficient binder ratio (*w/b*), the minimum and maximum permissible cement or effective binder content in the case of a risk of concrete corrosion due to a solution, the air content, sometimes the properties of the concrete components; - ***and on the other hand, the hardened concrete properties***, such as compressive strength class, the permissible chloride content or sometimes the frost resistance or frost and melting salt resistance, the air bubble system, water absorption, water tightness and abrasion resistance.

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God bless them both for a long time!

12. REFERENCED STANDARDS

ASTM D1498-14	Standard test method for oxidation-reduction potential of water
EN 196-2	Methods of testing cement. Part 2: Chemical analysis of cement
EN 206	Concrete. Specification, performance, production and conformity
EN 480-11	Admixtures for concrete, mortar and grout. Test methods. Part 11: Determination of air void characteristics in hardened concrete
EN 1744-1	Tests for chemical properties of aggregates. Part 1: Chemical analysis
EN 1899-2	Water quality. Determination of biochemical oxygen demand after n days (BOD_n). Part 2: Method for undiluted samples
EN 1917	Concrete manholes and inspection chambers, unreinforced, steel fibre and reinforced
EN 1992-1-1	Eurocode 2: Design of concrete structures. Part 1-1: General rules and rules for buildings
EN 12390-8	Testing hardened concrete. Part 8: Depth of penetration of water under pressure
EN 13577	Chemical attack on concrete. Determination of aggressive carbon dioxide content in water
EN 13755	Natural stone test methods. Determination of water absorption at atmospheric pressure
EN 14157	Natural stone test methods. Determination of the abrasion resistance
EN 15933	Sludge, treated biowaste and soil. Determination of pH
EN ISO 5815-1	Water quality. Determination of biochemical oxygen demand after n days (BOD_n). Part 1: Dilution and seeding method with allylthiourea addition
EN ISO 7980	Water quality. Determination of calcium and magnesium. Atomic absorption spectrometric method
EN ISO 10523	Water quality. Determination of pH
EN ISO 14911	Water quality. Determination of dissolved Li^+, Na^+, NH_4^+, K^+, Mn^{2+}, Ca^{2+}, Mg^{2+}, Sr^{2+} and Ba^{2+} using ion chromatography. Method for water and wastewater
EN ISO 15148	Hygrothermal performance of building materials and products. Determination of water absorption coefficient by partial immersion

EN ISO 17892-11	Geotechnical investigation and testing. Laboratory testing of soil. Part 11: Permeability tests
ISO 6060	Water quality. Determination of the chemical oxygen demand
ISO 7150-1	Water quality. Determination of ammonium. Part 1: Manual spectrometric method
MSZ EN 206	Concrete. Specification, performance, production and conformity (In Hungarian)
MSZ 260-4	Wastewater analysis. Determination of hydrogen ion concentration (pH value). Withdrawn standard (In Hungarian)
MSZ 260-9	Wastewater analysis. Determination of ammonium ion content. Withdrawn standard (In Hungarian)
MSZ 260-52	Wastewater analysis. Determination of calcium and magnesium content by complexometric method (In Hungarian)
MSZ 448-21	Drinking water analysis. Determination of total hardness, arithmetic of carbonate hardness and non-carbonate hardness (In Hungarian)
MSZ 448-23	Drinking water analysis. Determination of active, fixed, poise and aggressive for lime carbon dioxide (In Hungarian)
MSZ 1484-3	Testing of water. Determination of dissolved, suspended and total metals in water by AAS and ICP-OES (In Hungarian)
MSZ 1484-22	Water quality. Part 22: Determination of pH and pH in equilibrium state (In Hungarian)
MSZ 4798	Concrete. Specification, performance, production and conformity, and rules of application of EN 206 in Hungary (In Hungarian)
MSZ 4798:2016/2M:2018	Concrete. Specification, performance, production and conformity, and rules of application of EN 206 in Hungary. Amendment No. 2. (In Hungarian)
MSZ 4798:2016/4M:2023	Concrete. Specification, performance, production and conformity, and rules of application of EN 206 in Hungary. Amendment No. 4. (In Hungarian)

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